Towards Vision-based Safe Autonomous Landing of MAVs at Night

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***Abstract*— This paper is about vision-based navigation of Micro Aerial Vehicles (MAVs) at night. Despite it being dark almost half of the time, most of the work to date has addressed only daytime operations. Enabling autonomous night-time operation of MAVs with low SWaP on-board sensing capabilities is still an open problem in current robotics research. In this work, we take a step in this direction and study the problem in the context of vision-based autonomous landing at night using thermal-infrared cameras.**

I. Introduction

As aerial robots aspire for long-term autonomous operation for persistent inspection and maintenance missions, the ability to land safely and autonomously on a variety of structures becomes critical. Recently, vision-based algorithms amenable to SWaP constraints have successfully demonstrated on-board autonomous landing capability [1]. While substantial progress has been made, all the work has addressed daytime operation using standard visible-spectrum cameras, under normal illumination conditions. Enabling operations at night and low-illumination conditions would significantly enhance the tactical value of such a system.

In this work, we present a system for vision-based autonomous landing of MAVs at night using thermal-infrared (TIR) cameras. The nature of TIR modality makes them highly robust to low-illumination conditions (including total darkness) and other environmental effects such as the presence of fog, smoke and dust. However, these cameras have several characteristics that are challenging for vision algorithms - limited resolution, low SNR, rolling shutter and motion-blur distortion, etc. We model the TIR camera characteristics, study the performance of vision-based localization and mapping algorithms in the TIR domain and demonstrate an end-to-end system through real-world flight experiments in an outdoor environment.

II. Approach

We envision scenarios where the MAV must initially perceive the landing site from relatively far away (e.g. 10s of meters) and can refine its perception of the site as it approaches closer to it, as shown in Fig. 1. For state-estimation, we use a single nadir-pointed TIR spectrum camera, Semi-direct Visual Odometry (SVO) algorithm [2] to estimate the MAV's pose and fuse that with the data coming from an IMU [3]. The landing site detection algorithm then consists of two parts: the 3D reconstruction of the visible scene below the MAV using dense motion stereo algorithms, and the semantic analysis of the scene in order to search for potential hazard-free landing candidates. The output of the algorithms is a binary landing map in image space with underlying 3D coordinates in the world frame and a confidence measure for the landing site quality.

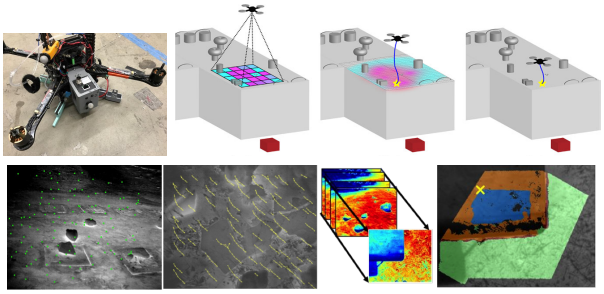

Fig. 1. (Top) Quadrotor equipped with a down-ward facing thermal-infrared camera and overview of the autonomous landing scenario. (Bottom) Feature detection, tracking and landing site estimation results across a sequence of frames during an outdoor flight experiment.

III. Experiments and Results

We integrated a FLIR System's A65 thermal infrared camera on an Asctec Pelican quad-copter and evaluated the onboard performance of our system in a natural outdoor environment, at different times of the day/night. Figure 1 shows qualitative results of feature detection and tracking, depth-map estimation and landing site selection during a flight experiment. Through extensive qualitative and quantitative experiments we demonstrate that vision-based autonomous landing of MAVs at night is possible at low flight speed. At higher speeds, state estimation experienced difficulty. We believe this was due to image gain variation as hot objects moved in and out of the image, which was not adequately handed by the Lucas-Kanade tracking algorithm implementation that assumed constant brightness. This issue remains to be addressed in the future.

References

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